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Renewable energy, poverty alleviation and developing nations: Evidence from Senegal

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Abstract
The desire to increase energy access remains a strong driving force for poverty alleviation in rural areas of developing countries. The supply of modern energy facilitates the improvement of human living conditions and the productivity of sectors. It also contributes by reducing the time spent, mainly for women and children, in collecting biomass and therefore can provide an opportunity for an increase in the education level of children and for women empowerment. This paper shows how renewable energy facilitates the improvement of the standard of living in a Sahelian developing country of Senegal. Using a life-cycle-cost approach while integrating an assessment of the environmental externalities, I argue that in remote rural areas where grid-connection is non-existent, photovoltaic (PV) renewable technologies provide suitable solutions for delivering energy services although wind technology has been considered as well. In this framework, policies promoting the adoption of clean technologies in developing nations like Senegal could be considered as being the main components on the agenda of poverty reduction.

Keywords: poverty alleviation, electricity access, renewable technology, environmental externalities, off-grid

1. Introduction

In rural zones of developing countries, access to energy is of paramount importance, as it increases the standard of living of rural populations by facilitating the struggle against poverty (Karekezi, 1997; 2002; 2003; Kaufmann, 2000; Martinot *et al.,* 2002). On the other hand, it also improves the quality of life with the creation of comforts for populations via the acquisition of goods such as radios, televisions and mobile phones (Jacobson, 2006; World Bank, 2003).

Considering particularly Sahelian countries,[1] energy access remains on average until now relatively low, while the renewable resources – wind speed and solar radiation potential – are widely abundant. The assumed endowment of renewable resources if harnessed could increase and improve energy access particularly in remote rural areas (Maiga *et al.,* 2006). According to that preceding assumption, a new and straightforward technique to analyze the cost-effectiveness of renewable technology's adoption in rural areas for poverty alleviation is required.

The purpose of this paper is to verify this assumption. After having shown impacts of energy access in poverty reduction, I will analyse how an increase of renewable energy could improve the energy access, therefore reducing the poverty's architecture. Of course, this preceding orientation assumes implicitly that an increase of energy access is considered as being a vector of poverty reduction. My assumption is not pin-killer while numerous studies have found the link between an increase of energy access and poverty alleviation in developing countries (UNDP, 2005; World Bank, 2007; Zahnd, 2009; Zomers, 2003; Cecelski *et al.,* 1979). The empirical case study utilizes the life-cycle-cost analysis. This methodology is performed to quantify and compare the monetary value of energy produced from electricity generation technology. It refers to the total cost of ownership of all selected technology over the lifetime of their operation. In doing so, I compare two energy-supply scenarios namely a business-as usual (BAU) and stand-alone renewable technology (RT) scenarios. In the first scenario (BAU), I assume that the energy supply is entirely provided through the classical diesel technology within a grid extension framework requiring, for instance, capital costs as well as costs relating to fuel utilization, operation and maintenance activities, transport and distribution costs. Finally, the last scenario – RT scenario – assumes that the estimated demand is wholly satisfied by the stand-alone decentralized renewable technology option through the use of a direct off-grid process. In this paper, two renewable technologies are considered namely a photovoltaic panel and a wind turbine. Moreover, the development of the scenarios is carried out under two different assumptions of fuel prices reflecting the case of the international high oil price affecting cost of fuels for power generation. This paper will be applied to the case of Senegal, a Sub-Saharan African developing country, for mainly two reasons. This country could offer a good representation of African developing countries in terms of investment venture on energy issues. Furthermore, the country will implement an energy recovery package for the development of renewable technologies within the first phase of a five-year period length 2008-2012. A survey carried out in the framework of the microgrids project,[2] allows us to work with data of potential energy demand assessed into the selected zones. Three regions have been selected for this project (Diourbel, Fatick and Kaolack). A survey was carried out in thirty villages for the determination of electrical power and energy need.

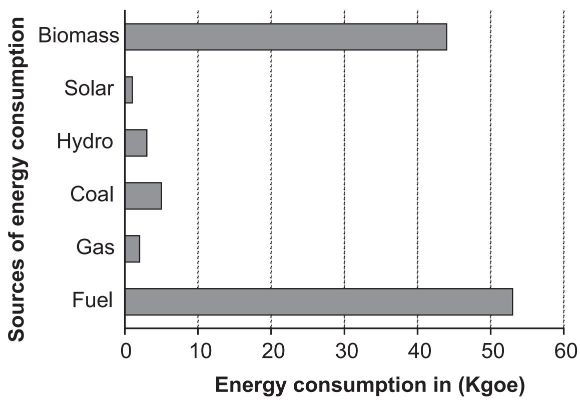
In order to investigate these issues, this paper will be divided in four main sections. The second section (section 2) presents the link between energy access and poverty reduction when the MDG[3] is considered as a core indicator of the standard of living. The third section (section 3) presents the methodology developed, while the last section (section 4) summarizes the mains results and common conclusions.

2. Energy access and poverty alleviation in Senegal

Like many non-oil producing countries in sub-Saharan Africa, the electricity sector in Senegal is characterized by a dependence on petroleum imports (see Figure 1). The share of energy produced from fossil fuels is higher compared to the existing energy sources. Moreover, the increasing effects of fossil fuel imports (78%) over the last six years have produced an imbalance in the balance of payment, since 42% of the exportation benefits are allocated to the payment of fossil fuel imports (SIE, 2007). The solar energy, hydroelectricity and energy produced from natural gas remains the smallest among all these available resources (Figure 1), although the country holds a suitable endowment in renewable energy resources (Youm, 2000; Camblong *et al.,* 2009; Alzola *et al*., 2009).

The relationship between energy access and poverty alleviation has been well investigated in the literature (World Bank, 2003; Dubois, 2007). Pachauri and Spreng (2003) provided the main conditions through which energy access could be linked to poverty reduction. They argued that the energy poverty could be defined referring to a threshold scheme capturing the energy poverty line. Foster et al., (2000) provided the energy poverty line applied to Guatemala. They argued that, following such representation, all consumers located under that line (threshold level) can be considered as 'energy poor populations' contrary to those located over which can be considered as being 'non energy poor populations'. Moreover, they argued that an increase of modern energy's access reduces the share of income devoted to energy consumption expenditures.

Dubois (2007) raised the necessity to overlap energy poverty into the utilitarian approach (Bentham, 1789), the 'primary good' approach (Rawls, 1971) and the 'capability' approach (Sen, 1983).[4] The utilitarian approach emphasizes on the 'mis-utilitity' generated by the lack of energy access.[5] Once one considers that the consumption of goods provides a satisfaction, any non-consumption of such goods could, all other things being equal, reduce the satisfaction. According to Rawls (1971) all humans should be able to possess 'primary goods' which reflect basic conditions for human dignity. Otherwise, people without these goods – primary goods – could be considered as poor. Assuming energy as a 'primary good' one can, *ceterus parebus*, define all peoples without energy access as 'energy poor'. The last point proposed by Dubois deals with the capability approach. The concept of capability was identified and proposed by (Sen, 1983) in order to consider heterogeneities among individuals. Once transferring the capability to the concept of energy poverty, the capability approach could be assimilated by the ability of households to consume adequate energy resources. Nevertheless, if one considers in detail economic structures in developing nations, these approaches have lacked to integrating specificities



Structures of energy resources consumption in Senegal in 2006

of developing nations (for example, the weight between urban – rural gap in terms of electricity access rate). Firstly, results stemming from the poverty line approach – therefore energy consumption – are very restricted while they did not provided insight results and therefore remained a random methodology. For example, in developing nations, the structures of energy consumption between urban and rural areas are different. Although there are important parameters affecting energy consumption in rural areas those are not included in the context of poverty line approach.[6]

Dealing with the poverty issue requires consideration of all components affecting standard of living. In this context, the multidimensional aspect of poverty had been recommended to better include socio-economic conditions of the poor (World Bank, 2003). For example, performing to the socio-economical conditions Krugman and Goldemberg (1983) have shown the impact of energy access into an increase share of the Human Development Index (HDI).

However, in our approach the Millennium Development Goals (MDGs) are considered as core indicators of poverty alleviation and therefore an improvement of the living standard. Furthermore, UNDP (2005) argued that the MDGs provide concrete, time-bound objectives for dramatically reducing extreme poverty in its many dimensions by 2015 – income poverty, hunger, disease, exclusion, and lack of infrastructure and shelter – while promoting gender equality, education, health, and environmental sustainability. These objectives were reaffirmed by all world leaders at the 2005 World Summit in New York. Moreover, it is widely argued that energy access has an impact on all MDG components (UNDP, 2005; World Bank, 2001; Kanagawa *et al.,* 2008). In developing countries, energy services allow cooking and heating, to develop economic opportunities as well as creating a social network. In order to explore impacts of renewable energy on the MDGs attainment, I first expose potential links between energy access and core components of MDGs.

Target 1: Energy vs poverty reduction vs income growth

Linking energy access to poverty reduction requires a preliminary definition of poverty. Considering the monetary approach[7] of poverty, the relationship between energy access and poverty reduction could be captured through a causality analysis.[8] Several empirical studies have been conducted using econometric instruments to analyze the causality effects between energy consumption and economic growth (Lee 2005; Ebohon 1996; Mozumder *et al.,* 2006; Odhiambo 2009; Wolde-Rufael 2008; Akinlo 2008). The bidirectional trend of a causality effect means that energy consumption draws economic growth and inversely an increase of economic growth draws energy consumption upwards. However, if the causality is unidirectional, the direction of the causality determines the adequate energy policy. Otherwise, if the multidimensional aspect is performed, socio-economic analyses provide better results about the link between energy access and the improvement of the standard of living of the populations (Krugman and Goldemberg 1983; UNDP, 2005; UN, 2005).

Target 2: Energy vs agriculture

The struggle against the malnutrition and food crisis in developing country requires an increase of agricultural productivity. Energy access within agricultural activities has for its part an important impact on agricultural yield's improvement (Singh, 1999). Because energy access in this sector facilitates irrigation, harvesting, and post-harvesting activities which lead to more mechanization of agricultural process which could increased food yields (Lee, 2005). Moreover the relationship between energy access and hunger is represented by the fact that energy in the form of heat represents 95% of the basis staple foods that form the human nutrition (UNDP, 2005).

Target 3: Energy vs education

In developing countries more than 2.4 billion peoples depend on biomass for their energy (UN, 2005). In Senegal, 40% of the energy supply is provided by the biomasses resources (SIE, 2007). Collection of biomass sources is mainly carried out by women and children. In this context, the link between energy access and education can be separated into two levels. On the one hand, energy scarcity creates pressure on children to spend time collecting fuel, fetching water and participating in agricultural work and therefore contributes to lowering school enrolments (UNDP, 2005). On the other hand, the availability of modern energy provides an opportunity to extend the daily time for course learning at night. Moreover, the socio-economic analysis carried out by the World Bank in the Philippines has shown the correlation between energy access and education results (ESMAP, 2002).

Target 4: Energy vs gender equality

The best way through which access to modern energy could impact on equity issues is by reducing time spent for collecting biomass. Since in rural areas of developing nations this activity is mainly carried out by women and children, and there is no doubt that the affordability of modern energy will empower these people., These critical hours used collecting biomass could be used in other income-generating activities such as commercial foods vending, which is facilitated by improved heating and lighting, agricultural processing using mechanical power, beer brewing, and many trading activities (UNDP, 2005).

Target 5: Energy vs health
The link between energy access and health in developing countries can be summarized on two levels. The burning of biomass for cooking, heating and energy utilization leads to health complications. Moreover, the World Health Organization (WHO) estimates that the impact of indoor air pollution on morbidity and premature deaths of women and children is the number one public health issue in many developing countries, particularly for the poorest segments of the population (UNDP, 2005). Furthermore, affordable clean energy allows the conservation of medicines in remote rural areas where medical services are relatively weak.

Target 6: Energy vs. Environment sustainability
The relationship between energy access and environment sustainability is complementary. On the global level, the affordability of modern clean energy diminishes the environmental damages caused by greenhouse gas emissions (GHG). For developing countries, clean energy access has more impact than simply reducing GHG. In fact, as developing nations experience over-exploitation of biomass, an increase of clean energy could reduce some environmental problems like deforestation (Heltberg *et al.,* 2000). Moreover, the deforestation acts directly to the decrease of agricultural productivity. It could also increase soil erosion as well.

3. Methodology
The goal of this methodology is to provide an alternative way to supply energy to remote rural areas in Senegal in order to reduce poverty. It is an extension of that used by Nguyen (2007). I introduced the analysis of external effects, so as to take into account the external costs stemming from the use of fossil fuels for the production of electricity. Furthermore, my approach is inspired by the life-cycle-cost9 analysis rather than simple comparison between capital costs. In the first step of this methodology, an analysis of selected technologies is performed. This permits determination of economic and technical factors. Furthermore, I include the emission factor, to determine the environmental costs stemming for the utilization of fossil fuel. Finally, environmental costs are integrated into an economic assessment to allow the determination of the levelized-electricity-cost. This latter criterion allows me to compare these two preceding scenarios namely the business-as-usual and the stand-alone off-grid scenario.

3.1 Analysis of selected technologies
The photovoltaic (PV) modules produce electricity by directly converting the sun's rays into electricity. The electricity produced is delivered in the form of D.C., which is perfect for numerous applications. However, that involves a transformation to alternating current if it is required to be introduced into a distribution network. The energy captured by a module depends on the surface, the nominal power of the panel and the duration of sun exposure. The latter varies according to latitude, season and time of day. However, taking into account the intermittent features of renewable technologies (Menanteau et al., 2003; Owen, 2006) the majority of photovoltaic (PV) modules are not connected to the distribution network use batteries. The latter permits storage of energy during periods of variable meteorological conditions, allowing balance between energy supply and demand. In rural areas of developing countries, this type of technology is appropriate for responding to the energy needs of the population (Karekezi, 2003).

In the case of wind turbines, kinetic energy is converted into electricity via the rotation of the turbine. The power captured by a wind turbine is a function of the square of its diameter and the cube of wind speed. When favourable meteorological conditions are present, wind technologies represent a good alternative method for supplying electricity. In the rural areas of the three regions studied (Kaolack, Thies and Fatick) small wind turbines are quite appropriate for the various end-use electrical appliances. Although more costly compared to those of conventional technologies, the costs connected to renewable technologies have decreased significantly during the last few years (Figure 2). Advances in research and development and the emergence of the assembly market in developing countries have lowered the cost of renewable energy technologies. Furthermore, it is argued that (Neij, 1999; ESMAP, 2007; Bordier, 2008) the learning process[10] of renewable technologies remains likely to decrease the cost in the next few years more than the last twenty years.

Three kinds of technologies are analysed. The decentralized renewable technology scenario is composed of a solar photovoltaic module with a capacity of 130Wc and a wind system with a capacity of 150W, while the business-as-usual scenario is based on the extension of the distribution network using a diesel group with a capacity of 450W.

This type of conventional technology has been selected because it corresponds to that being used currently in Senegal, for the production of electricity. Renewable technologies are in general use during projects phases in rural parts of Senegal. They were utilized because they are compatible with local conditions and the resources endowment. Technologies selected are evaluated by their costs.

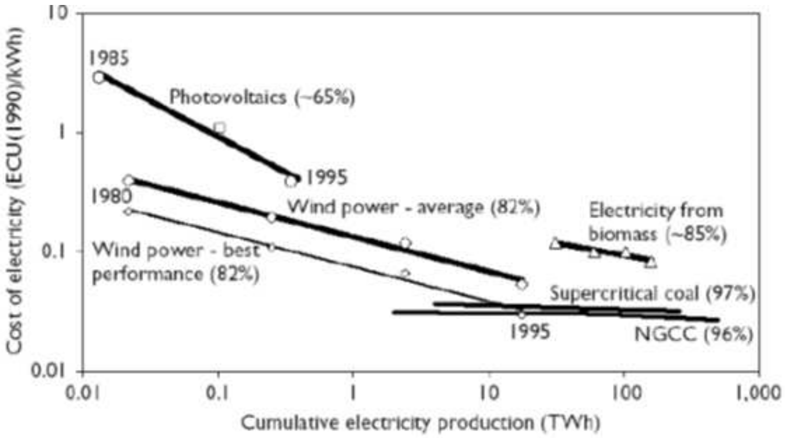


Figure 2: The learning rate of different renewable technologies
Source : Bordier (2008)

Table 1: Technical and economic features of selected technologies (production)
Sources: Compilation by the author based on various sources, including IEA, SEMIS, ENDA-TM, SENELEC[11]

	Pv tech	Wind tech	Diesel tech
Capacity	130Wc	150W	450W
Capital cost (F CFA)	350 000	160 000	185 000
Op and maintenance (FCFA)	1500	2000	9500
Life expectancy (years)	20	10	3
Battery capacity (Am)	100	100	
Battery cost (FCFA)	35.000	35.000	
Battery lifetime (years)	3	3	
Charge controller (FCFA)	25 000	25 000	
Controller lifetime (years)	10	10	
Fuel tank investment cost (FCFA)			15000
Tank lifetime (years)			3
Unit cost of delivered fuel (FCFA/m3)			210/m^3
Heat rate (KJ/KWh)			11 000
Note: Values are expressed in Francs CFA ($1 US = 489.207 F. CFA)			

Table 1 (b): Technical and economical features of selected devices (transport)
Source: ENDA-TM

Line medium tension	
Long-term marginal cost of electricity provided (cost of 1 kwh transported via the network) (FCFA)	36 000
Exploitation cost (CFA/km/)	240 000
Length (km)	10
Operating and maintenance costs (FCFA/km/year)	82500
Lifetime (years)	40
Transformer	
Cost of transformer (CFA/transformer)	2 000 000
Operating and maintenance costs for transformer (CFA/transformer /year)	60 000
Life Expectancy (year)	40
Line low tension	
Exploitation cost (CFA/km)	145 000
Operating and maintenance costs (CFA/km/year)	161 000
Connecting costs (CFA/clients)	22 500
Life Expectancy (year)	40
Loss (as a percentage)	15%

The latter includes capital costs, costs incurred during operating and maintenance, to which must be added environmental, transport, distribution and connection costs when referring to centralized business-as-usual option.

Capital costs are composed of the cost of equipment, including engineering costs, and all costs related to installation. On the other hand, operating costs vary according to the option considered. In the framework of a choice in favour of decentralization incorporating renewable technologies, operating costs are composed of the cost of operation and maintenance. While in the case of centralization, including the diesel group, operating costs are composed of costs of maintenance and costs allocated to the consumption of fossil fuels. These two following Tables (1 and 1bis) present the technical and economical characteristics of the selected technologies during the production and the transport of electricity.

However, a full analysis of the life-cycle-cost requires to taking into account environmental costs linked to the consumption of fossil fuel. Furthermore, external costs vary when one compares conventional and renewable technologies. For example, wind and photovoltaic systems can involve higher installation costs than diesel groups or gas turbines but they require relatively low operating and maintenance costs and do not involve the use of fossil fuels for their functioning. Following Nguyen (2007) and integrating environmental costs let us consider the expression of life-cycle cost as the following expression.

$$LCC = C_c + C_m + C_R + C_f + C_e \qquad (1)$$

Where *LCC* represents the life-cycle-cost

Capital cost (Cc)
Capital costs are those linked to the purchase of all system components, such as generators, PV units, batteries and extension costs for tension lines. They are generally defined as the initial acquisition costs for equipment before installation begins. These costs are exogenous for each option, centralized or decentralized, considered.

Operating and maintenance cost (Cm)
In a long-term perspective, technologies employed must include maintenance costs. These costs vary according to the options considered. This expense is low for renewable technologies as compared to conventional technologies.

$$Cm = AnnCm\left\{\left(\frac{1+i}{r-i}\right) * \left[1 - \left(\frac{1+i}{1+r}\right.\right.\right. \qquad (2)$$

Where *i* represents the interest rate, *r* the discount rate and *AnnCm* corresponds to annual operating and maintenance cost and finally *N* represents the number of years considered.

Replacement cost (Cr)
This represents the costs involved during the replacement of certain system components that have a lifetime shorter than that of the project. They can also include replacement costs related to wear and tear of certain devices.

$$C_R = \sum_{i=1}^{V}\left\{item \ \cos t * \left(\frac{1+i}{1+r}\right)^{N_T}\right\} \qquad (3)$$

Fuel cost (Cf)
These costs measure expenses carried out, during consumption of fossil fuels, for the operation of conventional technologies. The costs are zero for renewable technologies as deployed for a decentralized option:

$$Cf = AnnCf\left\{\left(\frac{1+Pf}{r-Pf}\right) * \left[1 - \left(\frac{1+Pf}{1+r}\right)^{N}\right]\right\} \qquad (4)$$

Where *Pf* represents the increasing share of fossil fuel price

- According to World Bank (ADI,12 2005) we assume that the? rate represents 4.5%.
- We assume an interest rate of 3%, as recommended by the BCEAO.13
- The inflation rate for fossil fuels, evaluated on the international database, assumes an annual average trajectory of 3% over the last sixty years.

Environmental cost (Ce)
This cost measures the external effects generated by the use of fossil fuels. The environmental cost can be represented by equation 5. This cost is also zero for renewable technologies as we consider these latter technologies do not emit pollutants during their electricity production periods.

$$Ce = HR * EF \qquad (5)$$

Where HR represents the *heat rate* and *EF* represents emission factor

3.2: Assessment of environmental externalities

It is argued that the assessment of environmental effects of energy production play an important role in the competitiveness of renewable energy technologies (Rabl, 2003; Bob van der Zwaan et al., 2004). The externality occurs if the economic activity of an agent has an effect on the well-being of another agent, in the absence of any commercial transaction (Baumol and Oates, 1988; Pearce and Turner, 1990).

In the framework of energy production, these external effects can be assimilated into the emissions generated during the different phases of electricity production, transport and distribution. In particular, these depend on the characteristics of the technology under consideration14 as well as the quantity of fossil fuels used.

Environmental externalities favour the diffusion of renewable technologies. As the latter does not contribute to greenhouse gas emission (GHG), it provides environmental benefits to remote rural areas in Senegal. Furthermore, it is often argued that the utilization of renewable technology can generate a good environmental effect in rural areas of developing countries (Spalding-Fecher and Matibe, 2003; Spalding-Fecher, 2005). However, I considered many effects within which renewable technology utilization could contribute to the environment well-being saving and standard of living improvement in rural areas in Senegal.

Table 2: Impacts of renewable energy adoption in rural areas in Senegal
Source: Inventoried by author

Environment • Lowering of pollution emissions • Decreasing a biomass consumption • Improvement in vegetation cover
Health • Reduction of respiratory problems • Reduction of infant mortality
Equity • Time gain for female population, following a reduction in time collecting wood for energy use
Education • Increasing of day length via night lighting • Time gain for children
Social • Creation of social ties (nighttime discussions, etc)

3.3 The determination of environmental cost

The evaluation of external costs is performed taking into consideration emission factors. Table 3 shows the different values of various emission factors of Senegal's energy sector. The evaluation of external costs is undertaken on the basis of the following values: 5.666§/ kg of SOx; 2.293§/ kg of Nox and finally 0.018 §/ kg of CO2. These latter, provided by El-Kordy *et al.,* (2002) represent estimations of the effects on both health and the degradation of the environment due to polluting emissions. These costs, when discounted, will be introduced into the life cycle analysis so as to determine the levelized-electricity-cost of these different technologies.

The assessment of environmental costs remains a difficult issue to accomplish in the context of developing countries, particularly in sub-Saharan Africa. Moreover, the well-know model inquiring environmental effects of energy production carried out in Europe (ExternE) required very intensive data collection. This model emphasized an impact pathway methodology required to consider all the steps of electricity vector diffusion from the extraction of fossil fuel until the waste disposal. Figure 3 depicts the process steps of the oil-to-electricity fuel cycle.

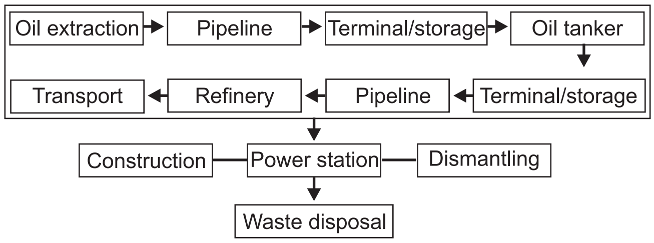


Figure 3: Pathway analysis of environmental effect in energy industry
Source: ExternE (1995)

At the moment it will be difficult to assimilate this model in the context of developing countries. The lack of quantitative data, the low level of environmental sensitivity, and the presence of a significant informal economy, made difficult this kind of analysis. This paper can be considered as the first intended to compute environment effects of energy production in Senegal

Table 3: Data on emissions factors
Sources: IPCC; SAS

	Oil	*Diesel*	*Natural gas*
CO_2 (kg/GJ)	36.7	37.05	28.05
Nox (mg/GJ)	0.15	0.0824	0.34
SOx (mg/GJ)	0.998		0.34

Note: Data on CO_2 emissions were collected at the IPCC Guideline 2006 for National Greenhouse Gas Inventories. This data corresponds to emissions factors focused on level I Emissions factors for other pollutants (Nox and SOx) come from the report of the Senegalese Association of Standardization (SAS). These correspond to emissions standards that the energy producer must respect under normal operating conditions.*

3.4 The assessment of energy demand

As explained earlier, the analysis of energy demand is based on a survey carried out within the context of the Microgrids programme. A survey was undertaken between September 18 and October 5, 2006 in three different regions of Senegal (Fatick, Kaolack and Thies). Three kinds of surveys have been conducted and included village surveys, household surveys and finally the technical surveys (Camblong *et al,* 2009).

Village surveys were carried out by interviewing people chosen by the chief of the village. The household surveys were mainly processed in two steps. A contingent evaluation was carried out, in the first step, with the aim to determine the willingness-to-pay for electricity access. Some 'strategic bias' was probably present so that the true willingness- to- pay was probably higher than that defined during the survey. Moreover, the second step emphasized collecting data concerning domestic behaviours related to energy consumption. Finally the technical surveys allow for listing of the driving forces and productions units (Camblong *et al.,* 2009). Thirty un-electrified villages were selected: Thirteen in the region of Kaolack, seven in Fatick and finally ten villages in Thies. Two criteria guided the choice of the selected villages. One criterion was the distance, all the villages are situated within a radius of 10 km from the SENELEC distribution network. To simplify, I assumed that the distance to grid-connection is lengthened to 10km. A second selection criterion was that related to the population of each village under study. The villages have been divided according to number of inhabitants, into three types of villages: small villages, medium-scale villages and large villages. Small villages are those with a population varying between 250 and 350 inhabitants, medium-scale villages are these varying between 500 and 750 inhabitants, and finally large villages are composed of 1000 to 1500 inhabitants. However, according to the nature and capacity of technologies considered in this paper, only the demands of small villages will be experimented in this paper. The technical capacities of the selected renewable technologies coupled with the meteorological conditions in the three different regions do not allow the satisfaction of medium-scale and large village requirements. Moreover, the Microgrids project aimed to build micro-networks, allowing the supply of electricity to remote rural areas, with capacities higher than those selected in this paper.

Obviously with higher technical capacities I could satisfy energy demand from all types of villages with various sizes. But in a decentralized stand-alone option, technologies selected can be quite different to those selected in a micro-network option. As this paper is dealing with stand-alone options, technologies should be socially acceptable and technically feasible. Furthermore, these selected technologies are not unrealistic, because they have been implemented during the PROVEN[15] project, which aimed to reduce poverty in rural areas of Casamance.[16] Their use has been mastered and they are compatible with local conditions and resources. They have acquired a level of social acceptability, which confers on them a fairly wide advantage in terms of dissemination.

Analysis of demand levels is based on the two principal steps. Substitute energy expenses are determined, in the first instance, so as to permit calculation of the level of electricity service that ought to be appropriate for one household. Moreover, as expressed earlier, a contingent assessment was conducted allowing the determination of monthly willingness to pay by households for electricity services. The combining of these two steps permits a characterization of energy needs of households. Table 4 presents the various estimates of demand for these three regions. We note that maximum consumption held in the region of Fatick despite the fact that only seven villages were investigated. The region of Kaolack, where one finds the largest number of villages investigated, presents the lowest levels of consumption.

Table 4: Estimation of electrical energy demand
Source: Microgrids Project Final Report

Region	Kaolack	Fatick	Thies	Total
KW/d	7.77	13.05	12.82	33.64

4 Results and discussions

The levelized-electricity-cost (LEC) was chosen as a decision criterion for the choice of competitive technology among the three technologies. This criterion remains the most widely used in terms of comparison of electricity production technologies, even if some suspicion remains about their reliability when uncertainty is included into technology generation investment (Roquest, Nuttal and Newbery, 2006). However, it represents the unit cost in kWh of electricity produced by a given type of technology. Its suitability over other criteria can be illustrated on two levels. Firstly, it compiles and integrates, beyond a simple comparison of capital costs, all operations, replacement, maintenance, transport and connection costs of the technologies considered. Furthermore, it also takes into account fossil fuel and environmental costs of conventional technologies. Total costs are considered in a discounted value taking into account the discount rate, interest rate, and the variation of fuel cost. In order to evaluate the levelized-electricity-cost I first determined the quantity of electricity provided. This variable appears in the discounted value.

$$QE_f = \frac{(kwh.produite)_j}{(1+r)^N} \tag{6}$$

QE_f represents the quantity of electricity provided by each type of technology; j the number of technologies employed (j = 1, 2, 3); r the discount rate and N the number of years under study.

According to Weisser (2004) the levelized-electricity-cost can be obtained while dividing the total cost from equation (1) by the quantity of electricity provided from the preceding equation (6).

$$LEC = \frac{LCC}{QE_f} = \frac{LCC}{\frac{(kwh\ .produite)_j}{(1+r)^N}} \quad (7)$$

Table 5: Levelized-electricity-cost of technologies employed in all three regions

	Kaolack	*Thies*	*Fatick*
Diesel Group (BAU)	757.88	570.45	410.98
PV Techno (RT)	102.865	73.4638	102.865
Wind Technology (RT)	115.813	122.23	115.813

I assume a line loss rate of 15% at the level of electricity distribution. I also assume that the transport network is made up by an average line of 9 km and a low line of 1 km.

The purpose of this paper was to show how resorting to renewable technology could facilitate energy access in remote rural areas in the developing country of Senegal. Assuming the interdependence between energy affordability and poverty reduction means to implicitly assume that policies in favour of renewable energy development are aimed at poverty reduction, then the multidimensional aspect of poverty has to integrate a new component which is to increase the policies in favour of clean energy development.

In the context of rural areas in Senegal, thirty rural areas situated in three different regions of Senegal (Thies, Kaolack and Fatick) were analyzed. Three types of technologies were considered within two different scenarios: A diesel generator dealing with the business-as-usual scenario and the renewable technology involving the stand-alone off-grid option for the renewable technology scenario. Our methodology informed by life-cycle analysis provided the levelized-electricity-cost for the different technology options.

However, according to metrological conditions in these selected areas, the levelized-electricity-cost (LEC) of renewable technologies (PV and wind) are identical for two regions included in the paper (Kaolack and Fatick).[17] Instead these regions present the same meteorological conditions. This uniformity at the level of meteorological issue justifies also the energy produced for renewable technologies, using the Weibull function, for the two above-mentioned regions. As a result, in terms of the cost associated with the life-cycle-process, these areas present the same value.

According to our results (see Table 5), I found that the photovoltaic technology presents a suitable option for increasing energy access, otherwise it could be a good alternative for helping the MDG attainment in Senegal.

Although few works are available on life-cycle analysis for the adoption of renewable technologies in Sahelian countries, my conclusions are similar to those obtained by certain authors in regard to other developing countries. In conducting a feasibility analysis for the adoption of renewable technologies in the case of Vietnam, Nguyen (2007) has shown the competitiveness of PV technology compared to conventional centralized-national network extension scenario. According to the same author, the competitiveness of the decentralized wind option depends on location. In analyzing the economic viability of the autonomous PV system in India, Kolhe (2000) concluded that: the PV system is comparable in economic terms to the diesel generator when demand is higher than 58kwh/day with an equal discount rate of 10%.

Similarly, Bugaje (1999) carried out a feasibility analysis of the adoption of energy technologies in Nigeria. As with the former example, three technological options were considered. The first consisted of performing extensions to the electricity grid so as to provide electricity services to remote rural areas. Moreover, the two remaining options (PV and diesel group) guaranteed the supply of energy services via a decentralized autonomous process. His analysis demonstrated the viability of the PV system compared to the two remaining options with a distance of 50 km including all selected villages. Finally, Bhuiyan et al. (2000) analyzed the feasibility of the adoption of PV technologies in Bangladesh. Using the net present value methodology, their conclusions are identical to that found by all of the above-mentioned authors; the levelized-electricity-cost of PV energy is lower than that related to conventional sources in zones where the electricity grid l grid is unavailable.

5. Conclusion

According to IAE[18] (2002), 1.6 million people in developing countries do not have access to electricity. Anticipating the future, they predicted that a large portion of this population would lack electricity services if the same trend of the electricity distribution continues. While having admitted the link between access to energy services and the improvement of living conditions, that means developing countries would wait a long time before having an improvement to their living conditions. That means that the attainment of the MDGs targets would be compromised.

The objective of this paper was to show how resorting to renewable technology could allow the attainment of the MDGs by facilitating energy access in remote rural areas in Senegal. I built two scenarios. On the one hand, the business-as-usual within with energy is provided by the grid-extension. I referred, on the other hand, to stand-alone renewable technology scenarios emphasize on a direct energy supply through a decentralized scheme in remote areas in Senegal. My results have shown the viability of the decentralized option of PV technology. My results demonstrated that the decentralized option using PV technology remains currently the optimal solution for dealing with poverty issues in the framework of the Microgrid project. From my results I can affirm that an optimal energy policy including renewable technologies could be an important component of poverty reduction target in Senegal.

Notes

1. Sahelian countries include Senegal, Mali, Benin, Burkina Faso, Mauritania, Niger, Chad, Gambia, Guinea Bissau and Cap Verde.
2. The Microgrids project was promoted and financed by the European Commission. Its goal is to promote the development of micro-networks and renewable resources for facilitating electricity access in rural areas in Senegal. This project was included in the context of poverty reduction scheme within the context of the Millennium Development Goal (MDG). This latter promoted by United Nations (UN) and developed countries targeted to reduce poverty depth in 2015, around the world developing countries.
3. Millennium Development Goal (MDG).
4. In Dubois (2007).
5. The 'utilitarism' approach can be considered as a form of 'consequentialism' contrary to the 'Kantism' from Kant's philosophy. According to that theory the maximum welfare is realized once the major part of people observes an improvement of their satisfaction. In this context 'energy access' is considered as an 'economic good'.
6. Parameters affecting energy consumption in rural areas could be – among others – gender, activities, habits, distances etc.
7. This approach defines the poverty as the lack of income. Specifically some threshold (1 and/or 2 $) are set up to characterizing the flexibility of poverty behaviour.
8. In this context energy access is assimilated to energy consumption and poverty reduction by an increase of economic growth. Comments are bypassed in this context, on the distribution issues which are more important when dealing with poverty reduction.
9. El-Kordy (2001) and Weisser (2004) have clearly outlined the advantages of the utilization of life-cycle-cost analysis compared to approaches based on a comparison of capital costs.
10. The learning process represents the lowering of cost production when the energy production doubled. For more details about the renewable technology learning process see (Neij, 1999).
11. International Energy Agency (IEA); Service de l'énergie en milieu Sahélien (SEMIS); ENDA-TM
12. African Development Indicators.
13. The BCEAO is the Banque Centrale des Etats d'Afrique de l'Ouest.
14. It is important to note that effects, such as the age of technology, types of fossil fuels used, efficiency of technologies and the installation of emission controlling equipment can have quite and impact on the pollution level from other pollutants except a carbon dioxide.
15. PROVEN was a project funded by the Fondation Energie pour le Monde. Like a lot of small-scale projects in Africa, they targeted to promote best practice approaches of off-grid rural electrification using renewable energies in rural Africa.
16. The south region of Senegal.
17. In fact these two regions make up part of the region of Saloum, located in the middle- west of the country, are very similar in terms of climatic conditions, in contrast to the Thies region, situated in the north-west of the country.
18. In (World Bank, 2006).

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